Domain Modeling for the Semantic Web: Assessing the Pragmatics of Ontologies

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Abstract. The Semantic Web requires the ability to express information in a precise-interpretable form so that software sharing data can also gain an understanding of the meaning of the terms describing the data. Referred to as the third component of the Semantic Web, ontologies are the means by which separate web components can share a common language and communicate in order to work together efficiently. However, there is a lack of understanding of ontology quality, specifically as it relates to selecting or creating an ontology for a Semantic Web application. Quality assessment systems are needed which include a way to assess the pragmatics, or usefulness, of a domain ontology for its intended purpose. This research analyzes the pragmatics of domain ontologies with respect to consistency, coverage, and usability to derive a set of evaluation metrics, which are represented in a framework. An empirical evaluation illustrates the usefulness of the metrics.

Keywords: Ontology assessment, Interoperability, Metrics, Semantic web, Domain ontology, Ontology evaluation, Pragmatics, Domain modeling.

1 Introduction

The Semantic Web is an extension of the World Wide Web in which entities of the web share information and work together without dependence on human intervention [3, 17]. For the Semantic Web, these concepts are defined using domain ontologies to model the entities and the relationships between them within a specific knowledge area. Semantic Web pages are tagged with classes from the ontology to allow for interoperability with other web entities. Terms and relationships found in Semantic Web applications use formal ontologies to make the semantics explicit so that the consistency of the knowledge can be assured, contributing to automated reasoning [3]. Interoperability between ontological resources is required to automatically analyze data across different repositories, supporting knowledge discovery [5, 17].

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Being able to assess the ability of an ontology to model its domain is dependent on the ontology being of sufficient quality, not only syntactically and semantically, but also pragmatically. Pragmatic quality is the measure of how well an ontology contributes to accomplishing the purposes and goals of an application [19]. When developing or selecting an ontology for a Semantic Web application, it would be helpful to have a means of evaluating candidate ontologies to assess their pragmatic quality in an attempt to ensure that the ontology selected is best fits the goals of the application.

The objectives of this research are to: 1) develop a framework for pragmatic assessment metrics for domain ontologies, and 2) implement the framework in a prototype that scores an ontology's usefulness for a specific Semantic Web application. The contribution is to derive rules related to pragmatics for the construction and selection of domain ontologies to advance the Semantic Web.

This paper proceeds as follows. The next section outlines prior work related to the role of domain modeling for the Semantic Web. Section 3 presents a set of metrics for assessing domain ontology quality on a pragmatic level. Section 4 details an evaluation that was done to determine the affectiveness and feasibility of the metrics. Section 5 discusses the insights gained by the metric evaluation. Section 6 summarizes and concludes the paper.

2 Related Research

2.1 Domain Ontologies

Ontology deals with the nature of existence and theories about the nature of the fundamental types of phenomena that occur in the real world [21]. A domain ontology captures and represents information specific to a domain and contributes to "enabling interoperability across heterogeneous systems and Semantic Web applications" [5, p. 34]. In that sense, a domain ontology is a model of a the relationships between the terms in the domain. In general, modeling involves the construction of a conceptual representation of the application domain of an information system [21]. Then, a representation, often graphical, is used which captures some features of a real-world domain that assists in the design, implementation, maintenance, and use of an information system [2].

With respect to the Semantic Web, we need domain ontologies that have, in a given vocabulary, the meaning of a term expressed and understood by defining: 1) all the properties that can be used on it; and 2) the types of those objects that can be used as the values of these properties [24]. For the Semantic Web, a suitable ontology is needed for a given application. However, selection of ontologies from the many that are available is challenging due, for example, to different ways of representing domain ontologies, and domain ontologies being constructed independently, for different people, using different resources [11, 12].

2.1 Semantic Web Interactions with Ontologies

There are many advantages to using a domain ontology for a Semantic Web application to model its particular domain. First, domain assumptions are made explicit, allowing for knowledge reuse. Second, the use of an ontology provides a way to encode the knowledge and semantics that a machine can understand, furthering interoperability between systems and making large-scale machine processing easier [24]. Data interoperability is facilitated because the use of an ontology as part of a Semantic Web application promotes knowledge reuse and formally represents the knowledge related to a given domain. Web searches are more powerful when web entities use semantic tags to specify term meanings, allowing a search engine to find related concepts and perform reasoning tasks rather than simply seaching for specific key terms [24].

Domain ontologies are represented in ontology description languages such as rdfs and OWL that are especially designed to represent the type of complex relationships often found in natural language. [13]. The OWL language was created to express relationships among classes defined in different documents on the web and to construct new classes based on the unions and intersections of existing classes. The OWL language can also add properties to the terminology used in a web document such as requiring that all members of a class have a particular property, or whether certain properties may not be held by members of a particular class. The knowledge represented in OWL is logic-based so computer programs can interpret the meaning and verify consistency without requiring human interaction [24].

Semantic web entities interact with ontologies through the use of semantic tags assigning meanings to the contents included on the web pages through a process called Semantic Markup. Figure 1 illustrates how concepts from an ontology can be added as semantic tags to web pages.

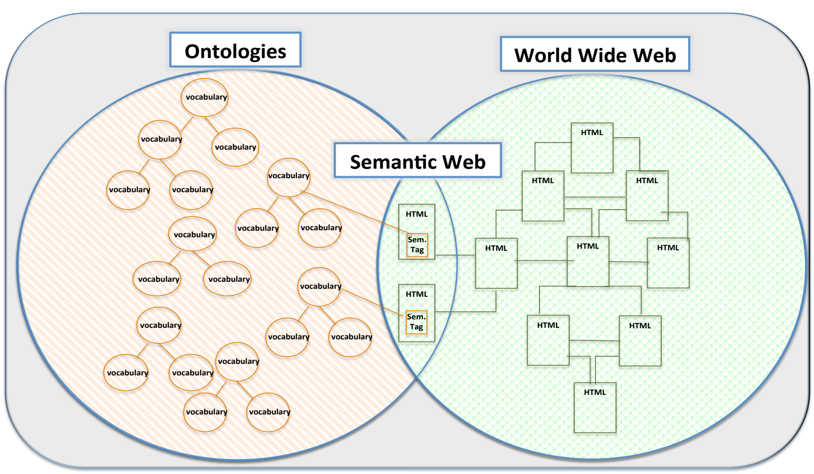

Fig. 1. Ontologies formalize web page terminology

2.2 Ontology Quality

Ontologies, like all models, must support context-dependent reasoning and provide means for collaborative interaction [19]. Ontology design, however, is a creative process, with many possible ontologies possible for a particular domain [24]. When selecting an ontology to use for an application, it is important that the chosen ontology is of sufficient quality. For ontologies, identifying which characteristics indicate that an ontology is of high quality, is a challenge [21].

Any information system representation can only be considered "good" if it maximizes the meaning that can be obtained about the real-world concepts it represents and if humans are able to extract this meaning [8, 21]. Therefore, the usefulness of an ontology can be assessed by its ability to model its domain and its ability to be interpreted and applied by humans.

Ontologies represent a shared understanding about concepts and relationships of a domain. They help manage and exploit information. Ontologies clarify meaning among users in the form of explicit knowledge that can be executed by software. More efficient reasoning is possible if a high-quality ontology is employed by an automated application [20].

Bera et al. [2] discuss the importance of context for model creation and use, stressing that the assessment of an ontology's quality cannot be separated from its context. Choi et al. [5] argue that, to be useful, an information system must consistently and accurately model applications. Ontologies are increasingly considered to be a key factor for enabling interoperability across heterogeneous systems and Semantic Web applications [5, 17].

Terms related to the use of ontologies to model a domain can differ. For example, some researchers use the terms conceptual modeling and domain modeling interchangeably, although they are not synonymous for many applications. Domain modeling focuses on ensures that all terms and the relationships between them are accurately represented possibly even including disjoint relationships and specific attributes of the terms [12], whereas conceptual modeling provides a higher level of abstraction of the concepts of a domain [21]. Table 1 defines these and other terms relevant to understanding the role of ontologies.

Table 1. Terminology related to ontologies and their use in the Semantic Web

Term	Definition
Agent	A program that collects Web content from diverse sources, processes the information and exchanges the results with other programs [3]
Annotation	An explanatory note added to an ontology
Class	A category of things having some property or attribute in common and differentiated from others by type or quality
Conceptual Modeling	Construction of a conceptual representation of the application domain of an information system [21]

Consistency	Whether it is possible to obtain contradictory conclusions from valid input data [10]
Coverage	Quantity of terms and axioms covering a desired text [16]
Domain	A specified sphere of activity or knowledge [1]
Domain Modeling	A way to describe and model real-world concepts and the relationships between them for a specific area of interest [15]
Domain Ontology	A formal description of concepts in a domain of discourse which may also include properties, features, attributes and restrictions on those concepts [15]
Ease of use	A means of allowing the ontology's content to be easily incorporated into a software system [22]
Ontology	A specification of a representational vocabulary for a shared area of discourse [12] A formal naming and definition of the types, properties, and interrelationships of the entities that exist [24]
OWL	Ontology Web Language – A family of knowledge representation languages designed for use with ontologies [13]
Pragmatic Quality	The correspondance between a model and the audience's interpretation of the model's meaning [14]
Pragmatics	The study of how languages are used for intended functions depending on the purposes and goals within a community [19]
Semantic Markup	The use of semantic tags to reinforce the meaning of the information in web pages and web applications [24]
Semantic Query	A query that allows for the retrieval of both explicitly and implicitly derived information based on syntactic, semantic and structural information contained in data [6]
Semantic Web	The web of meanings [24]
Semantic Tag	Meta-data assigned to a piece of information on the Semantic Web that describes an item and allows it to be found again by browsing or searching [24]
Usability	The level of annotation and meta-data available in an ontology [9]

2.3 Pragmatics

Stamper et al. [18] defined pragmatics as a measure of how well signs are able to express the intentions of their user. This definition can also apply to ontologies, which are made up of signs designed to represent concepts in a domain. Thalheim [19] defines pragmatics as the study of how languages are used for intended functions depending on the purposes and goals within a community of practice. This definition can be expanded to ontologies, which are models of the language used for a specific domain. Together these two definitions express how well an ontology fulfills the intentions of its users. For the Semantic Web, the users are the developers of web applications between which an ontology conveys the intended vocabulary. Assessing the pragmatic quality, therefore, can be thought of as a measurement of how well the ontology fulfills the goals of the applications that employ it, with that goal being interoperability with other applications.

3 Pragmatic Ontology Assessment

The assessment of an ontology's quality cannot be separated from the context in which it is intended to be used. For Semantic Web applications, the context is the ability to accurately express shared terms with other applications. Therefore, in this research, three metrics are proposed to assess the pragmatics of an ontology in terms of its usefulness for that context. These metrics, evaluate consistency, coverage and usability, with each measuring an essential aspect of usefulnes. Together, they provide an overall evaluation of an ontology's pragmatic quality.

3.1 Consistency

An ontology is not useful if it has redundancy or cyclical errors [21]. These errors prevent full covereage of a domain because cyclical errors cause some portions of the ontology to be unreachable and other portions to contain more than one conflicting definition.

Figure 2 shows an example of an ontology containing a consistency error caused by a class/subclass relationship in which each is in a different disjoint class. In this example, a Soy Sausage Pizza cannot be a subclass of both Sausage Pizza and Soy Pizza because a Soy Pizza is a subclass of Vegetarian Pizza, which is clearly disjoint from a Meat Pizza, and a Sausage Pizza is a subclass of Meat Pizza. These types of inconsistencies are difficult to find, but obviously problematic.

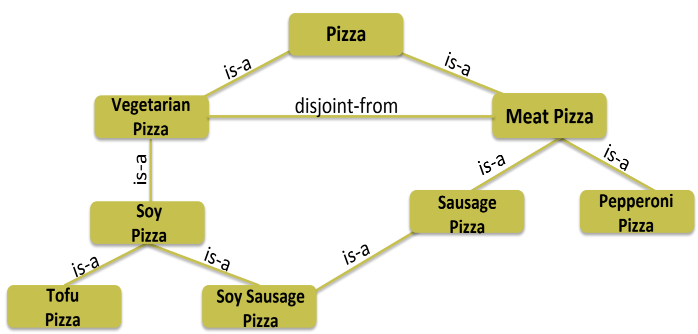

Fig. 2. Soy Sausage pizza illustrates disjointness inconsistency

The Consistency metric assesses whether an ontology is free of these type of errors and is computed as the ratio between the number of consistency-error-free relationships and the total number of relationships in an ontology. A perfect consistency score, therefore, would be 1.0. In equation 1, if R represents the total number of relationships in an ontology and E represents the number of consistency errors in the ontology, then:

$$Consistency = (R - E) / R \quad (1)$$

3.2 Coverage

Coverage assesses the balance between covering enough of the domain so that concepts which are part of the domain are not omitted without covering such a broad area that too many irrelevant concepts are also included in the ontology. The submetrics for Comprehensiveness and Relevance represent these opposing ideas.

- *Comprehensiveness* is defined as how well an ontology covers all concepts required for a particular domain. In general, it is simply the size of the ontology relative to the size of other ontologies under consideration. Larger ontologies are more likely to cover all the concepts necessary for full coverage of a domain. Let *C* be the number of classes in this ontology and *M* the maximum number of classes for an ontology under consideration. Then:

$$Comprehensiveness = C/M \qquad (2)$$

- *Relevance* is the balancing metric to Comprehensiveness in that it assesses whether all concepts of the ontology are relevant to the desired domain. An ontology that receives the highest assessment of relevance, does not include any irrelevant concepts. Let *R* be the number of classes in an ontology relevant to a set of keywords. Let *C* be the total number of classes in the ontology. Then:

$$Relevance = R/C \qquad (3)$$

Domain modeling requires that an ontology's coverage is neither too broad nor too narrow, balancing relevance with comprehensiveness to accurately model the desired domain. Figure 3 shows the competing requirements in achieving the optimum concepts to be included in the ontology. It is important that the domain ontology cover the entire domain without missing any concepts, but does not become unwieldy from being overloaded with irrelevant concepts.

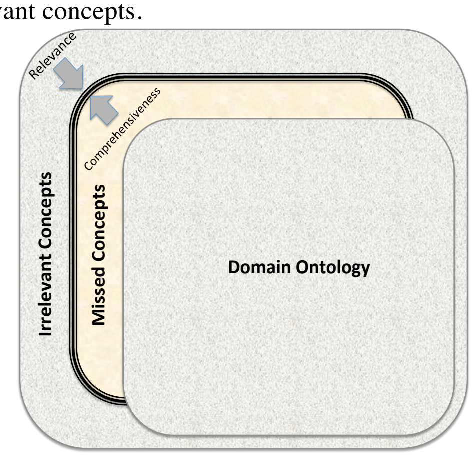

Fig. 3. A domain ontology should balance comprehensiveness and relevance

The concepts of comprehensiveness and relevance work together to assess how well the balance between too broad and too narrow has been reached; therefore, the assessed values for the metrics of Comprehensiveness and Relevance are weighted to compute the overall value for the Coverage metric. The computation of whether an ontology accurately covers the intended domain is formalized is equation 4.

$$Coverage = w_1 * Comprehensiveness + w_2 * Relevance \quad (4)$$

3.3 Usability

Usability assesses the level of annotation in an ontology [9]. Annotations and comments in ontologies provide: 1) guidance to human users when examining the ontology; and 2) additional information for ontology matching tools to link the data in the ontology. Because of the complexity of language, meta-data is needed to provide insight into the meaning of the terms in the ontology. Ontologies containing little or no annotations are less useful. Figure 4, shows a comment from the Wyner et al.'s Legal Case Ontology [23] clarifying the meaning of the term "Issue" in the intended context of the ontology.

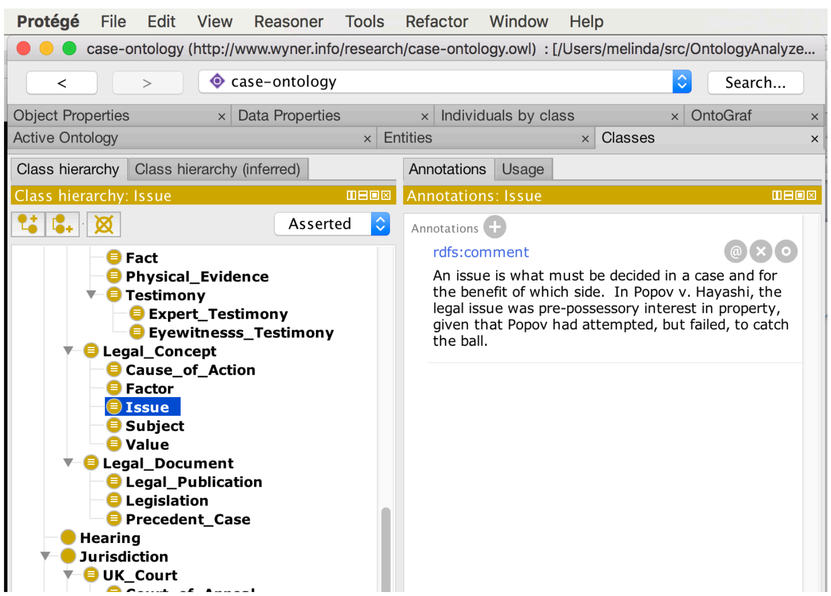

Fig. 4. Example of descriptive annotation for term in an ontology

Usability, in this research, is assessed by: 1) the number of comments and annotations in the ontology; and 2) the length and placement of those annotations. Longer comments are more useful in expressing ideas [23]. Comments located close to the class they are describing, as opposed to all in one place, are most useful in discerning meaning

[13], so both length and placement are considered when computing Usability. Usability is the weighted average of the ratio of comments to classes and the ratio of locations to comments. The best score an ontology could receive on usability is 1.0 which would be achieved when an ontology has a comment or annotation for each class and those comments are evenly distributed throughout the ontology. Usability is calculated as shown in equation 5. Let A represent the number of annotations in the ontology. Let L represent the number of different locations in the ontology that contain an annotation. Let C represent the total number of classes in the ontology. Then:

$$Usability = w_1 * (A/C) + w_2 * (L/A) \quad (5)$$

4 Exploratory Evaluation

To test the validity of the consistency, coverage, and usability metrics for assessing the quality of ontologies, we conducted an exploratory investigation in two phases using experts from four separate domains.

4.1 Phase 1

Participants were experts recruited from: building construction, culinary arts, law, and mathematics. These domains were chosen to incorporate unique terminology and to allow for the different types of tasks that might be required in Semantic Web applications. The participants were given two tasks: 1) rank ontologies related to their domain; and 2) rank the relative importance of each of the metrics in making these rankings. The domain experts were given a simple questionnaire on the metrics that identified the ontologies under consideration and provided definitions for the three attributes. During phase 1, the researcher took notes of the time the experts spent examining each ontology and the comments that were made.

Task 1. The participants were each shown several ontologies related to their area of interest and asked which one they would consider using if they were planning to create a web application and wanted to define the terms. They were encouraged to talk aloud as they compared the ontologies using the Protégé application [15] with the OntoGraf [7] visualization plugin. They were instructed to rank the ontologies in order of preference and to explain their reasonings for the ranking.

Task 2. The participants were then asked to consider the three pragmatics metrics and asked whether these attributes (consistency, coverage and usability) were qualities important for the selection of an ontology. They were instructed to rank the metrics in order of importance in making their assessment of which ontology would be preferred by them if they were creating a Semantic Web application.

Phase 1 Results. All four of the experts were in agreement that the metrics would provide useful information about ontology quality, but the relative importance of each differed greatly among the domains. Each of the attributes for consistency, coverage, and usability was found to be of paramount importance by at least one expert, but also considered to be of very minor importance by an expert in a different domain.

The Building Construction expert, for example, considered that coverage of the domain is the most important attribute. In particular, not only should all terms be included, but the addition of new terms and features should be easy to perform. In the Building Construction field, the relationships between features and materials is continually changing as new materials and new purposes for those fields continue to be explored. He did not consider annotations to be very necessary in the Building Construction field. He considered consistency important, but not as important as coverage of the domain and the ability to add new terms.

The legal domain expert agreed with how each of the three metrics were obtained and stated that, for his domain, the inclusion of annotations and comments is essential. He considered this to be more important than coverage and consistency because the precise meaning of legal terms is often a subject of dispute between legal experts. Therefore, it is essential that any term be clearly defined and examples be included from actual court cases where possible. Consistency was less important because, with the disagreement between meanings of terms in the legal field, it is not unlikely that consistency errors may be found, even in carefully built ontologies. One challenge is the fact that different legal systems, for example between the United States and the United Kingdom, use different legal terms to mean different things. Therefore, since one term could have a completely different meaning in another legal system, ontologies must be well-annotated in addition to being well-designed.

The mathematics expert considered consistency to be the most significant attribute for an ontology because the mathematics field allows for no possibility of misconstrued terms. The culinary arts expert, on the other hand, rated consistency of minor importance because what is meant by different cooking terms can vary between types of cuisine.

Figure 2 shows the disparity between the rankings of metric importance mentioned by the domain experts. For each domain, a value of one indicates the most important attribute, while a value of three indicates the least important attribute.

Table 2. Results of assessment metric importance ranking

Domain	Consistency	Coverage	Usability
Building Construction	2	1	3
Culinary Arts	3	1	2
Law	2	3	1
Mathematics	1	3	2

4.2 Phase 2

Given the varying importances of the metrics, an additional phase of testing was needed to ensure that the three pragmatics metrics would be able to accurately assess the quality of an ontology if their computations were performed in the order of priority deemed most applicable for a specific context. To perform these determinations, an Ontology Pragmatic Assessment (OPA) framework was developed, as shown in Figure 5. The framework's purpose is to take a set of ontologies to be considered for a domain and assess the ontologies by applying the three pragmatic metrics in the priority order input by the user, assuring that, at each stage of the assessment, an acceptable level of quality is reached.

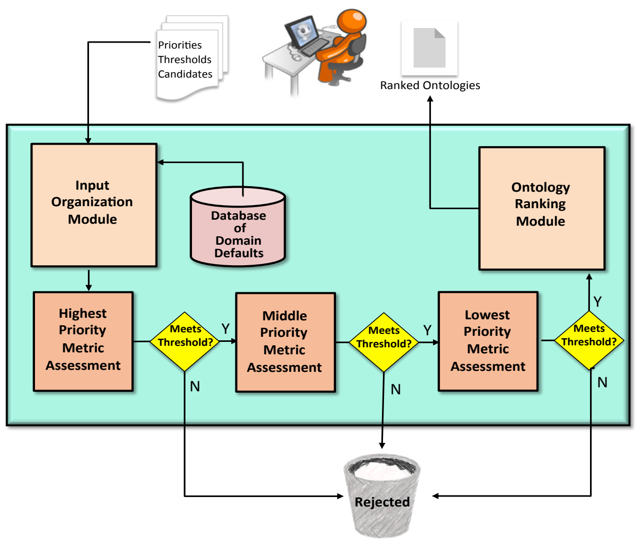

Fig. 5. Architecture of Ontology Pragmatics Assessment (OPA) framework

Framework Architecture. The OPA framework accepts input in the form of a set of domain ontologies for consideration, the list of the three metrics with assigned threshold and weighting values, and a set of one or more keywords identifying a specific domain. At each step of the framework an ontology may be rejected if it does not meet an acceptable standard for that metric. as shown in the lower portion of figure 5. The metrics are calculated in order of highest to lowest priority. Each of OPA's modules serves a distinct purpose in the assessment process.

- **Input Organization Module.** This module accepts four items of input from the user: 1) a set of ontologies stored in OWL format, 2) a set of importance weights for the three pragmatics metrics, and 3) a set of three threshold values for the quality level associated with each of the pragmatics metrics, and 4) a set of keywords representing the desired domain. This module checks the input data and supplies default values where needed, and then passes these values to the metric assessment modules to ensure that the system evaluates the metrics correctly.

- **Priority Metric Assessment Modules.** These three modules assess the quality of the candidate ontologies using the priorities and thresholds received from the Input Organization Module. At each module, the pragmatic metric of that priority is computed and compared to the threshold value for an acceptable level of quality on that metric. If any of the ontologies receive a score less than the acceptable level the ontology is rejected.
- **Ontology Ranking Module.** This module determines a final score for each of the non-eliminated ontologies corresponding to the weighted average of the results from each of the three assessment modules. The module then produces a ranking list by score order that is given as output to the user.

Phase 2 Method. To test the OPA framework, the original sets of candidate ontologies examined by the four domain experts served as input. Additional information was input in the form of the priority weights of the three metrics as determined by the domain experts, and the threshold values input by the domain experts. For each domain, the ontology selected by the system matched the ontology the expert had preferred during manual examination of the ontologies. Table 3 summarizes the steps followed in the framework's development and evaluation.

Table 3. Steps for framework development and evaluation

Domain expert is shown a set of candidate ontologies and three metrics
Domain expert ranks the metrics in order of importance to his/her domain
Domain expert ranks the ontologies in order of preference
Framework is developed to evaluate the ontologies based on priority order
Candidate ontologies are entered into the framework for evaluation
System results are compared to the domain expert's results

Phase 2 Results. In all instances, the ontology selected by the system corresponded to the choice made by the domain expert during the examination of the ontologies. For example, the Building Construction expert selected the FreeClassOWL building materials ontology [25] over the other contruction and building material ontologies considered. The OPA framework, by weighting Coverage higher than both Consistency and Usability as designated by input selections, resulted in the same selection after applying the metrics.

6 Conclusion

As noted by Bertossi et al. the assessment of the quality of a data source is context dependent. That is, the notions of "good" or "poor" data cannot be separated from the context in which the data is produced or used [4]. Although the context of the development of a Semantic Web application is obviously important for providing an assessment of "goodness," this research shows that the domain of discourse is also important. What constituted a high-quality ontology for one domain could differ significantly from what would constitute a high-quality ontology for a different domain.

This paper has discussed the need for, and challenges of, selecting good domain ontologies for Semantic Web applications. To identify appropriate domain ontologies for a particular problem, both the context and task must be considered. This research has developed a set of metrics for the pragmatic aspect of domain ontology assessment and implemented the metrics in a framework for ranking domain ontologies based on a user's needs. The framework was tested by applying it to different domains. Future research is needed to extend the metrics and to integrate the pragmatics assessment aspects with other needed qualities of ontology assessment, such as completeness or accuracy.

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